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ABSTRACT

This paper discusses the results of two studies both dealing with spatial abilities and training. The first investigated the kinds of spatial strategies and personal experiences, both nonacademic and academic, that distinguish students preparing for high spatial careers from others. The second study focused on the effectiveness of spatial training incidentally given during a 2-month period in mathematics courses. This study was integrated with the first insofar as it was hypothesized that spatial abilities could be enhanced by academic experiences. Three hypotheses were investigated: (1) students preparing for high spatial careers would perform better in spatial reasoning; (2) high spatializers would report more spatially enriching nonacademic and academic experiences; and (3) high spatializers would employ more efficient spatial strategies, such as the use of mechanical drawing schemas to compare flat figures to three-dimensional analogues and rapid holistic rotations to compare three-dimensional block-like objects. Results indicate that there were significant gains for subjects in three-dimensional visualization and three-dimensional orientation performance. Appended is the Vandenberg Mental Rotations Test (MRT). (KR)

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SPATIAL STRATEGIES AND SPATIAL TRAINING IN THE COLLEGIATE CURRICULUM

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ABSTRACT

High spatial abilities are thought by some researchers to be prerequisite for entrance into a wide range of scientific careers. Hence, more career options are accordingly opened to high spatializers. The kinds of spatial strategies and personal experiences, both nonacademic and academic, that distinguish students preparing for high spatial careers from others were investigated in the first of two exploratory multivariate studies. The second study focused on the effectiveness of spatial training incidentally given during a two-month period in mathematics courses. This study was integrated with the first insofar as it was hypothesized that spatial abilities could be enhanced by academic experiences.

A total of 126 undergraduate students in eight intact classes of a large university participated in the first study. Hypotheses were that (1) students preparing for high spatial careers would perform better in spatial reasoning; (2) high spatializers would report more spatially enriching nonacademic and academic experiences; and (3) high spatializers would employ more efficient spatial strategies, such as the use of mechanical drawing schemas to compare flat figures to three-dimensional analogues and rapid holistic rotations to compare three-dimensional block-like objects. Correlational analysis confirmed the first two hypotheses. Yet, stepwise multiple regression analysis provided a more complicated interpretation of the findings, particularly where strategies were concerned.

Two pairs of duplicate classes in a medium-sized university participated in a quasi-experimental second study. Results of correlated t tests showed that there were significant gains for both groups (n=45 and n=38) in three-dimensional visualization and three-dimensional orientation performance. These findings, however, should be interpreted with caution because of practice effects and experimental mortality.

Introduction

Besides being able to speedily mentally rotate and reflect three-dimensional objects and to rapidly cognitively fold up flat objects to hollow space objects for sheer enjoyment, high spatializers have more career opportunities open to them. The latter fact has been supported by a number of researchers whose contributions are recorded in Smith (1964) and McGee (1979). Specific among those occupations requiring top-level spatial ablity are engineeer, scientist, draftsman, and designer (McGee, 1979).

Since spatial ability is linked to vocational opportunity, two questions arise. First, what is spatial ability? Second, what are the schools doing to train students in spatial reasoning?

The answer to the first question is complex because there is lack of consensus among researchers regarding the nature of spatial ability. Nonetheless, a succinct operative definition serves as the focal point to the answer.

> Spatial ability may be defined as the ability to generate, retain, and manipulate abstract visual images. (Lohman, 1979, p.188).

How spatial ability is decomposed is the problem. Two independent researchers and reviewers failed to reach agreement on the number of spatial abilities. Lohman (1979) posited three spatial abilities: spatial relations, which is linked with mental rotation of objects and to a lesser extent, speed of performance; spatial orientation, which relates to various imagined perspectives in space by either the stimulus or the problem solver; and visualization, which is associated with paper folding and puzzle completion tasks. McGee (1979) specified two spatial abilities -- spatial visualization and spatial orientation. The former ability involves mental manipulation, rotation, twisting, and inverting of pictorially presented visual stimuli. The latter ability encompasses the aptitude to remain unconfused by the changing orientations of a presented configuration in relation to the positional orientation of the observer.

In a more recent work, Lohman (1988) recognized the existence of ten distinct spatial factors, or abilities. These are: general visualization, spatial orientation, flexibility of closure, closure speed, speeded rotation, spatial scanning, perceptual speed, serial integration, visual memory, and kinesthetic ability. His recent

position was based in part on the detailed categorization of a massive number of paper-and-pencil spatial tests by Eliot and Smith (1983).

Yet, the most appealing decomposition of spatial ability follows that of McGee. Ekstrom et al. (1976) stated that visualization requires mental manipulation of a figure by its restructuring into components; whereas, spatial orientation requires manipulation of the whole figure. The studies reported in this paper follow that way of thinking. It should be noted, however, that Ekstrom et al. (1976) did not consider the spatial factor to be bifurcated into visualization and orientation. They stipulated other spatial factors.

The answer to the second question is also complex, not to mention enormously factual. Therefore, only a brief sketch is provided. Classroom subjects which typically incorporate spatial content are mathematics and science. It is within those disciplines that spatial thinking can be developed (Smith, 1964; Bishop, 1978; Piemonte, 1982; Smith et al., 1983; Lappan et al., 1984).

On a large scale, the National Council of Teachers of Mathematics (1989) has advocated the inclusion of spatial thinking in geometry, beginning in kindergarten through grade 4. Also, the NCTM suggests that spatial reasoning be continued in grades 5 through 8. Finally, at the high school level, the NCTM recommends that increased attention be given to computer explorations of two-dimensional and three-dimensional figures to develop students' spatial reasoning within the geometry curriculum.

Furthermore, a number of companies provide spatial materials to schools. One striking publication called SPACES (1982) is available through Dale Seymour Publications. This is a spiral-bound notebook of activities, some of which are spatial, which was developed by The Lawrence Hall of Science at the University of California, Berkeley specifically for elementary and secondary school students. SPACES is an acronym for Solving Problems of Access to Careers in Engineering and Science.

On a more personal note, individual researchers have attempted to rectify the unfortunate situation of allowing spatial abilities to develop by chance. My own account of a study follows shortly. First, a few studies in spatial training are highlighted.

Connor and Serbin (1980) cited evidence based on their own research and that of others that spatial ability is trainable at various age levels. In one of their own studies, Connor and Serbin (1985) found that spatial training for several hundred eighth graders improved only their scores on Space Relations of the DAT and Card Rotations. Training was ineffective for Cube Comparisons, Form Board, and Paper Folding. (The latter four examinations are part of the ETS Kit of Factor-Referenced Cognitive Tests.) This finding suggests that two-dimensional spatial orientation could be easier to teach than three-dimensional orientation or two- and three-dimensional visualization. That particular study, however, employed a half-hour training session. Therefore, the length of the training period could have impeded improvement of certain spatial skills.

A slightly longer training session, which was one hour in duration, was reported by McGee (1978). In a study involving several hundred university undergraduates, a shortened version of Vandenberg's Mental Rotations Test was administered before and after training. The influence of taking the same test twice confounded the training effect. Nonetheless, females were noted to have benefitted less than males from training.

An even longer spatial training study of approximately five hours was conducted with thirty-six undergraduate education majors randomly assigned to two treatment groups. One group studied algebraic structures in their mathematics class by way of a verbal approach. The other group was exposed to a combined verbal-spatial visualization approach. Results of the study failed to support the stipulated hypothesis that spatial visualization ability and success in a Number Systems course are positively correlated. Also, the class taught via the verbal approach did better in a structures exam than the verbal-spatial group. The researcher (Battista, 1981) attributed this unexpected finding to the fact that algebraic structure material is seemingly processed in a verbal-symbolic mode.

A recent study by Ferrini-Mundy (1987) incorporated a longer training period. In this study, several hundred college students practiced with six spatial-training modules during an eight-week period while they were enrolled in a calculus course. Audio-visual slides and audiovisual-tactual manipulatives were used during this self-study program. The most salient result was that the practice sessions improved the ability of the women to visualize when solving problems about solids of revolution. It was concluded that spatial training could benefit women more than men in certain areas of calculus.

Pallrand and Seeber (1984) examined the relationship of spatial abilities to achievement in introductory college physics. Spatial performance by an experimental group, which received 11 hours of special spatial training during a ten-week period, was compared to that of both a control and a placebo group. The researchers found that all groups improved their visual-spatial skills at the end of their semester course in physics. However, the pretest to posttest gain of the experimental group was the greatest among the groups studied. Pallrand and Seeber concluded that the physics course itself may have enhanced the perception, orientation, and visualization skills of the subjects.

A study that concluded to the trainability of visuo-spatial skills was conducted by Lord (1985). An experimental group of college students were provided 30-minute spatial training sessions per week during a semester. The training consisted of mentally envisioning and drawing pictures of bisected three-dimensional geometric figures. Posttest scores showed the experimental group performed markedly better than a control group, which did not receive spatial training.

Although the foregoing small collection of spatial trainability studies has manifested some conflicting results, the teaching of spatial skills has intellectual promise. Since that is the case, educational institutions should incorporate spatial ability training into their curricula wherever suitable.

This paper describes two exploratory, multivariate studies conducted in 1988 while I was teaching at two universities in Pennsylvania. Research findings were to be included in a book on spatial reasoning.

The primary purpose of the first study was to detect the kinds of spatial strategies that are employed by college students preparing for high-spatial careers. A secondary purpose was to ascertain whether such strategies were learned formally in the school or informally out of school.

The purpose of the second study was to determine whether spatial reasoning could be enhanced incidentally through mathematics courses high in spatial content. Individual spatial gains made during several weeks of training were considered critical to such a determination.

METHOD

Study One: Spatial Strategies

Subjects.

Participating in this study were 126 undergraduate college students, from freshmen to seniors, in eight intact groups. The average age, based on 123 subjects, was 21.0 and the standard deviation was 5.0. There was a speech communication class; two architectural classes, one of which was advanced; four engineering classes; and one computer science class. This latter group was my own class. With the exception of the speech communication class, which served in a control capacity, the other classes were chosen because the students, for the most part, were thought to be high spatializers.

Design.

Fourteen variables, two of which were posited for identification only, were selected for this exploratory study. The twelve operational variables included the following: three-dimensional spatial orientation score, known as MRT score; three-dimensional spatial visualization score, known as SDT score; mental computation score, know as WNMCT score; age; gender; class; major; nonacademic background experience; academic background experience; MRT strategy; SDT strategy; and WNMCT strategy.

A correlational design was selected to measure strength of association between career objective and spatial reasoning and between spatial reasoning and background experiences. Multiple regression was employed to explain the variation in spatial reasoning effected by other variables, such as major, experiential background, strategies, age, and gender.

Materials.

Three-dimensional orientation was measured by Vandenberg's Mental Rotations Test (MRT). This paper-and-pencil examination consists of two parts, each with ten items based on the block-like figures conceived by Roger N. Shepard for his chronometric study of reaction time. (See Shepard and Cooper, 1982; Shepard and Metzler, 1971). Test-retest reliabilities, based on large samples of subjects ranging in age from 14 to adult, after a year or longer interval ranged from 0.83 to 0.70. Split-half reliability, corrected by the Spearman-Brown formula, based on a large

group of undergraduate college students who took the highly speeded version of the test, 3½ minutes per part, was 0.79. Also, the test shows satisfactory construct validity, measured by its correlations with similar and dissimilar tests (Vandenberg and Kuse, 1978).

Three-dimensional visualization was measured by ETS' Surface Development Test (SDT), which was modeled on Thurstone's test of the same name. (See Thurstone, 1938.) The examination consists of two parts with six items per part. Reliabilities for the test were 0.90 for a sample of 146 college students and 0.92 for a sample of 86 Army enlistees (Ekstrom et al., 1976).

Mental arithmetic was measured by a self-constructed instrument entitled the Whole Numbers Mental Computation Test (WNMCT). This test includes two parts, each consisting of 16 items. The first part contains eight addition and eight subtraction problems. The second part contains eight multiplication and eight division problems. Two-week test-retest reliabilities were 0.69 for a group of 15 graduate students whose average age was 28.47, s=7.33 and 0.80 for a group of 25 undergraduate students whose average age was 21.2, s=0.84. The instrument exhibits content validity. Nonetheless, it has not been tested for construct validity.

Another self-constructed instrument, called the Spatial Reasoning Questionnaire, was used to gather data for the noncognitive variables in the study, such as age, gender, class, major, and experiential background. Three additional sections of the questionnaire measured spatial and arithmetic strategies. These sections featured both forced choice and free response recall for collection of retrospective measures. The instrument has not been validated.

Procedure.

With permission of each of the instructors of the participating classes, the researcher entered the classrooms and explained the purpose of the study. After each test was distributed, subjects were shown respective examination cover sheets by way of an overhead projector and given directions regarding how to take the exam. Consistency was maintained from classroom to classroom.

Exams were administered in fixed order, beginning with the MRT. Next, the SDT, the WNMCT, and the questionnaire were distributed. Respective times were three minutes per part for the MRT, six minutes per part for the SDT, five minutes per part for the WNMCT. Times were monitoried by an

accurate Swiss stopwatch. Personal data and retrospective measures were collected by questionnaire after all cognitive tests had been taken. The entire length of the testing session was about 55 minutes per class. All testing was conducted within a two-week period in April of 1988.

Study Two: Spatial Training

Subjects.

A total of 60 undergraduate elementary education majors in two twin classes of MAT 102, Mathematics for Elementary Teachers II participated in the study. Joining them were 59 undergraduate students, most of whom were liberal arts majors, in two twin classes of MAT 103, Introduction to Mathematics. The average age of the combined MAT 102 sample was 21.9, s=4.4. The average age of the combined MAT 103 sample was 21.0, s=3.5, based on 52 subjects.

Design.

This was a quasi-experimental design which focused on individual student gains in spatial visualization and spatial orientation over a two-month period. Correlated t tests were used to assess the amount of gains for each spatial ability for each of the combined groups.

A total of twenty variables, only one of which was stipulated for identification, was created for this study. The four primary variables were cognitive in nature. These were SDT#1 score, MRT#1 score, SDT#2 score, and MRT#2 score. Other variables were age, gender, class, major, experiential background, self reports for each of the cognitive variables, understanding of directions for each of the cognitive variables, and final exam grade.

A secondary study, correlational in design, was undertaken to evaluate the strength of association between the cognitive variables and the personal and recollection variables. This study was intended to complement the experimental study.

Materials.

For both the pretest and the posttest, ETS' Surface Development Test was used to assess three-dimensional spatial visualization; Vandenberg's Mental Rotations Test, for three-dimensional spatial orientation. Two self-constructed questionnaires also were designed for the study. The first, Spatial Reasoning questionnaire, Part I, collected personal

data, experiential data, and personal opinions after completion of the two pretest spatial exams. The second, Spatial Reasoning Questionnaire, Part II, gathered personal opinions after completion of the two posttest spatial exams. Neither instrument has been validated.

Procedure.

In early October of 1988, subjects in four intact classes, which were my classes, were administered the following pretests in the fixed order shown--SDT,MRT, and my own questionnaire (Part I). The two spatial tests were administered and timed by the same conditions as those cited in Study One. The only differences were in the order of administration of the spatial tests and that an overhead projector was not used. Total testing time per class was about 55 minutes.

Following completion of the battery of tests, spatially enriching lessons were taught in a natural way as they occurred in sequence in the respective texts (Graham, 1984 for MAT 102; Berlinghoff & Grant, 1988 for MAT 103). Specifically, the prospective teachers were taught such topics as rigid motions of two-dimensional plane figures, geometric constructions, and measures of geometric solids. A number of geometric solids were used for demonstrating volumes and surface areas. The liberal arts students were taught the mathematics of infinity, rigid motions of plane figures, and two-and three-dimensional taxi-cab geometry. Rigid motions were demonstrated via transparencies on an overhead projector for special emphasis.

By mid-December, about two months after the pretests, the same two speeded spatial tests were again administered in the same order, now as posttests, under the same conditions as before. And, another home-made questionnaire (Part II) was given. Again, the total testing time per class was about 55 minutes.

RESULTS

Study One: Spatial Strategies

Data were processed by SPSS-X (SPSS, 1988; Norusis, 1988). An IBM mainframe connected to an IBM PC served as the hardware facility.

Tables 1 through 6 supply relevant results from this study. Sample pages from the tests, shown in the Appendix, provide information concerning their content.

Marking schemes for the tests were as follows: (1) MRT, two points for each problem with exactly two correct choices; one point for each problem with exactly one correct choice and no other alternative marked; zero points for one correct and one incorrect choice, or for no correct choices (2) SDT, four times the number right minus one times the number wrong -- to avoid fractional answers after application of a correction for chance (3) WNMCT, five times the number right minus one times the number wrong, as above. Scores on the WNMCT represent complete scores summed over both parts. Some scores were disqualified if pencil marks were seen on the examination sheets.

Table 1 shows descriptive statistics for each of the eight classes in the study. As expected, the senior-level architecture class performed best in the two spatial tests, and in the multiplication/division section of the WNMCT. However, one of the engineering groups, in engineering graphics, did best in mental computation across the four operations.

Table 2 shows the results of all classes combined on the three tests. Age was included for informational purposes only. Percentages of the maximum score for each of the tests were: 46.4%, MRT; 74.3%, SDT; and 31.7%,WNMCT. These percentages show that the MRT and WNMCT were too difficult for their respective time limits for the combined group.

Measures of the personal and strategy variables were collected by questionnaire. Age was recorded correct to the nearest tenth of a year; gender was coded as 0 for males and 1 for females; class was coded as 1 for freshman, 2 for sophomore, 3 for junior, and 4 for senior; major was coded as 0 for liberal arts or education, 1 for mathematics or computer science, 2 for chemistry, physics or chemical engineering, 3 for architectural engineering, and 4 for architecture. The coding in the latter category reflected my opinion that the more spatial the major, the higher its value should be.

The two experiential variables can be considered, as those listed above, personal variables. A point was awarded for each nonacademic source of spatially enriching activities cited. The total score on this variable was summative. Several suggestions specified on the questionnaire were constructing airplane and home models, working with construction toys, and disassembling and assembling automobile engines. Scores for academic background variables were obtained in the same way as those for the nonacademic background variable. Several suggestions specified on the questionnaire were clock building in elementary science, constructing molecular models in chemistry, building polyhedral models from cardboard in mathematics, and taking a mechanical drawing course. In the case of the latter citation on a completed questionnaire, not 1 but 4 points credit toward the total score were awarded.

Two facts should be noted. First, zeros were recorded for "N.A." (not applicable) answers. Second, a missing values number, 999, was written into the SPSS-X computer program so that missing information would be ignored in the processing. The missing values code 999 applied to all operative variables except age. The latter variable was flagged by 99.9.

The strategy variables were coded according to the quality of strategies asserted in the literature or to my own ideas. For example, the MRT is a test with an interesting history. Whether mental rotation is an analogue or a propositional process has concerned a number of researchers (Corballis, 1982). One of the proponents for the propositional side is Pylyshyn. He has theorized that, regarding mental rotation and scanning, mental images are processed as symbolic encodings of rules, beliefs, and goals (Pylyshyn, 1981). In contrast, Shepard (see Shepard and Cooper, 1982) has argued that mental rotation is an analogue process. Yet, mental imagery could embrace both analogue and propositional elements. This compromise position has been explained by Corballis (1982). Therefore, the following forced choice scheme was used for the MRT: 0 for guessed answers; 1 for subvocal, i.e., verbal or propositional processing; 2 for analogue whole rotation strategies. A 3 was recorded for analogue partial rotation or some other sophisticated or mixed strategy as expressed in a free response alternative.

For the SDT, a 0 was recorded if the subject cited guessing; a 1 was recorded for mental folding; a 2 was recorded for application of mechanical drawing procedures to the task of mental folding. Also, a 3 was recorded if the subject cited, in the free recall option, mixed strategies, such as a combination of mechanical drawing techniques and mental folding where appropriate.

The Whole Numbers Mental Computation Test was coded as follows: 0, for computing answers indirectly, i.e., by selecting the most reasonable answer from the response set; 1, for computing sums and differences by the typical algorithms but products and quotients by selecting plausible alternatives. A 2 was recorded for computing sums and differences by the typical algorithms, and products by mentally seeing nonlinear alignment of partial products, and quotients by educated guessing given the alternatives. A 3 was recorded for a strategy consisting of all of the above with the exception of division, for which quotients were processed by mental reconstruction of partial quotients with concomitant remainders. A 4 was awarded for other spatial approaches, such as whole numbers analogue with distributivity, which were expressed in the free recall option.

The Whole Numbers Mental Computation Test was included in the study because I thought that individuals who could quickly and accurately process symbolic information in their heads may provide enlightenment on how spatial designs are processed. There was some supporting evidence for this association by way of substantial correlations between arithmetic computations and spatial visualization found in several studies (Fennema and Sherman, 1978; Baker, 1987).

In Table 3, correlations between spatial orientation and major and spatial visualization and major suggest that those preparing for high spatial careers perform better in these two important three-dimensional skills. Also, high spatializers have experienced more spatially enriching activities, both inside and outside the classroom. Although the three cognitive variables are significantly correlated, ability to do speed mental arithmetic is not dependent on either major or out-of-school experiences.

For a closer inspection of the cognitive scores and strategies, Table 4 shows that only ability to do speed arithmetic is associated significantly with strategy. Thus, better arithmetic processors are able to retain numeric symbols in short-term memory and see partial products line up to compose total products. The reason for the weak negative correlation between spatial visualization and its corresponding strategy is because a higher weight was awarded to a lower, more analytical, strategy. This suggests that rapid mental folding of the ETS figures which is similar to analogue processing of the Vandenberg objects, is a more efficient strategy. Corroboration of this conclusion is provided by the negative correlation between MRT score and the SDT strategy. Nonetheless, because the p values ($p = 0.442$ and $p = 0.493$, respectively) were nonsignificant, the conclusion is tentative for this sample.

Prior to conducting the multiple regression analysis for each dependent variable, assumptions underlying the model, such as normality and linearity, were checked (Norusis, 1988). Since violations did not appear to be serious, MR was executed. (See Pedhazur, 1982.)

Tables 5 and 6 show the results of stepwise multiple regressions for spatial orientation and spatial visualization, respectively. Several combinations of predictors were used in trial runs prior to selection of that set of variables that parsimoniously best explained the variances in each criterion variable. The best single predictor of MRT score was SDT score (R Square = 0.31703, F less than 0.001). On step 2, gender increased the predictive powers of spatial visualization ability by almost nine percent (R Square = 0.40498). Nonacademic background experience accounted for an almost seven percent increase in explanatory power (R Square = 0.47321). Collectively, however, the eight variables shown in Table 5 explain more than 48½ percent of the variance in spatial orientation ability.

Table 6 shows that a combination of eight variables best explains the variance in spatial visualization, which is almost 41½ percent. However, as a single predictor MRT score accounted for over 31 percent of the variance in SDT score (R Square = 0.31437, F less than 0.001). Its explanatory power was increased by almost four percent by the WNMCT score (R Square = 0.35378), which was entered on step 2. Nonetheless, this latter predictor lost its significance as a predictor when the other six selected predictors entered the equation. Notice that academic experience, with a relatively high beta weight, is an important, though nonsignificant, predictor of spatial visualization score.

Study Two: Spatial Training

Tables 7 and 8 show a similar trend for both combined mathematics groups, MAT 102 and MAT 103, respectively. First, there are increases in the means and in the accompanying variances from pretest to posttest for both spatial skills. Second, some students in both classes chose not to take the posttests because participation in this exploratory experiment was voluntary.

So that the results of the correlated t tests would not be compromised because of experimental mortality, several independent groups t tests were conducted to ensure that the dropouts performed the same on both spatial tasks in the

pretests as those who remained in the study. Yet, for MAT 102, a homogeneity of variance test for SDT showed violation of this assumption ($F(14, 44) = 2.123$, $p < 0.05$). Therefore the nonparametric Mann-Whitney U-test was conducted instead of the parametric independent groups t test. Results, however, supported the hypothesis that the "stayers" and "leavers" were from the same population ($U = 325.50$). For all other tests, the homogeneity of variance assumption was supported. Hand-calculated tests were based on Winer (1971, pp.38-39), Pagano (1986, pp.220-223), and Darlington (1975, p.333). All subsequent group t tests showed nonsignificant t values. These were $t = 1.054$ for the MRT, MAT 102; $t = -0.004$ for the SDT, MAT 103; and $t = 0.033$ for the MRT, MAT 103.

Coding schemes for Questionnaire I, which accompanied the pretests, were the same as those for Study One for gender and class. With regard to major, only two weights were assigned, 0 for education and 1 for liberal arts. The latter was a general category distinction that in reality complemented education. The weights for nonacademic and academic background experiences also were assigned as specified in Study One. Two other retrospective items served as other operative variables. These were the self report item on test performance which was coded as 0, 1, 2, 3, or 4 according to very poor, poor, about average, good, and very good, respectively, and the directions item, which was coded as 0 for not fully understanding the directions or 1 for understanding the directions. These two variables applied to both the SDT and the MRT.

Tables 9, 10, 11, 12, 13, and 14 are support tables, which should be read in pairs. Odd-numbered tables refer to performance of the combined MAT 102 classes; even-numbered tables, to MAT 103. Several interesting findings are depicted. For example, Tables 9 and 10 show that in the pretests, the younger students in both groups processed the Vandenberg figures more efficiently. Also, both WCU groups, like their PSU counterparts, showed a tendency for male dominance in the MRT. Furthermore, the two spatial variables were significantly correlated for the liberal arts group but not for the education group.

Tables 11 and 12 show that spatial visualization aptitude increases significantly with school-related experiences. The same, however, is not true for spatial orientation aptitude. Moreover, the correlations between both spatial variables and directions in the pretests for both groups suggest that the students, for the most part, did understand how to take the tests.

Tables 13 and 14 relate to the posttests and Questionnaire II. Basically, three important measures were collected for data analysis in the retrospective instrument. First, subjects were requested to rate their SDT posttest performance in comparison to their pretest performance. Codes awarded after forced choice selections were made were 0, 1, and 2 for poorer, the same, and better, respectively. The code 3, however, was recorded if the subject noted that he/she did better because of the practice effect. A 4 was given for those students who cited that one of the spatially enriching activities in the intervening classes helped them do better; 5, for more than one spatial activity. Second, the subjects were requested to do the same for the MRT. Third, the subjects' spatial scores were associated with their final exam scores. Since the final exam tapped spatial content, this measure was meaningful to the study.

Table 13 shows that the education majors significantly evaluated their performance in the SDT but not in the MRT. The reverse is true for the liberal arts classes (see Table 14). Further, only spatial visualization for the education majors was an important skill for performance in their final exam; whereas, both spatial visualization and spatial orientation were important toward grade in the liberal arts final examination.

Lastly, tables 15 and 16 were prime to the study. Table 15 shows significant correlated t test values for both spatial variables for the education group ($t, 44 = 8.07$, p less than 0.001 for SDT; $t, 44 = -2.38$, p less than 0.05 for MRT). Table 16 shows similar results for the liberal arts group ($t, 37 = -5.41$, p less than 0.001 for SDT; $t, 37 = -2.80$, p less than 0.01).

It should be noted that among the MAT 103 students, 52 students took the pretest; 7 students took the posttest, but not the pretest; 38 students from the first group took the posttest. Therefore, the seven subjects in the posttest group were dropped from the study. Also, correlated t tests were selected for statistical analysis because Pagano (1986) stated that the correlated t test is more sensitive to changes in performance than the independent t test if r is high. For the MAT 102 data, $r = 0.7490$ between SDT #1 and SDT #2 and $r = 0.6087$ between MRT #1 and MRT #2. Both correlations were statistically significant at p less than 0.001. For the MAT 103 data, $r = 0.9163$ between SDT #1 and SDT #2 and $r = 0.7675$ between MRT #1 and MRT #2. Both correlations were statistically significant at p less than 0.001.

TABLE NOTES

1. **Tables 1-6** concern Pennsylvania State University.

2. **Tables 7-16** concern West Chester University.

3. Numbers in parentheses in **Tables 3, 4, 9-14** are the number of scores in the sample for zero-order Pearson correlations.

4. In **Tables 3, 4, 9-14** a dot is printed in each case where an a priori probability cannot be computed.

5. One-tail probabilities are reported in **Tables 3, 4, 9-14.**

6. T ratio significance is reported for two-tail probabilities in **Tables 5 and 6.**

TABLE 1
DESCRIPTIVE STATISTICS BY CLASS

1. SPEECH COMMUNICATION -- EFFECTIVE SPEECH

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	13.73	151.82	29.26	17.63
Std.Dev.	7.75	69.07	15.54	12.03
Median	12.50	187.50	25	18
No. of Subjects	22	22	19	19
Range (scores)	0 to 28	0 to 240	0 to 60	-7 to 39

2. ARCHITECTURE -- DESIGN AND PLANNING THEORY II

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	18.55	194.45	35.93	14.48
Std.Dev.	9.33	44.68	16.83	10.94
Median	16	212	34	14
No. of Subjects	31	31	30	27
Range (scores)	0 to 38	10 to 240	7 to 80	-4 to 40

3. ARCHITECTURE -- ARCHITECTURAL DESIGN & ANALYSIS

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	23.14	219.43	24.57	22.00
Std.Dev.	5.46	17.62	10.24	12.52
Median	22	230	23	20
No. of Subjects	7	7	7	7
Range (scores)	21 to 30	191 to 240	13 to 40	1 to 30

TABLE 1 (cont'd)

4. ENGINEERING MECHANICS -- STATICS

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	21.91	180.09	28.91	18.55
Std.Dev.	11.18	71.72	15.35	10.60
Median	22	215	29	19
No. of Subjects	11	11	11	11
Range (scores)	2 to 38	50 to 240	6 to 55	4 to 35

5. ENGINEERING MECHANICS -- STRENGTH OF MATERIALS

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	20.80	180.40	34.78	19.11
Std.Dev.	8.89	63.05	11.62	7.06
Median	18.50	207.50	29	19
No. of Subjects	10	10	9	9
Range (scores)	9 to 38	68 to 235	24 to 54	11 to 29

6. ENGINEERING GRAPHICS -- ENGINEERING METHODS AND GRAPHICAL COMMUNICATION (GROUP 1)

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	19.85	179.00	40.05	21.72
Std.Dev.	7.14	48.96	15.76	14.89
Median	19.50	189	35	24
No. of Subjects	20	20	19	18
Range (scores)	9 to 38	37 to 240	20 to 69	-10 to 45

TABLE 1 (cont'd)

7. COMPUTER SCIENCE -- INTRODUCTION TO PROGRAMMING TECHNIQUES (IN PASCAL)

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	18.00	161.63	31.00	13.83
Std.Dev.	6.61	61.70	11.59	7.65
Median	19	167	30	16
No. of Subjects	8	8	6	6
Range (scores)	8 to 26	80 to 240	17 to 49	2 to 23

8. ENGINEERING GRAPHICS -- ENGINEERING METHODS AND GRAPHICAL COMMUNICATION (GROUP 2)

	MRT	SDT	WNMCT	
			A/S	M/D
Mean	18.93	182.31	32.19	15.73
Std. Dev.	7.87	54.92	12.84	11.93
Median	20	192.50	33.50	16
No. of Subjects	15	16	16	15
Range (scores)	4 to 30	20 to 240	2 to 55	-1 to 48

a Classes are ordered according to the temporal order in which the tests were administered.

b Test ranges are as follows:
MRT, 0 to 40; SDT, below 0 to 240;
WNMCT (A/S), below 0 to 80;
WNMCT (M/D), below 0 to 80.

TABLE 2
POOLED DESCRIPTIVE STATISTICS -- PSU CLASSES COMBINED

MRT SCORE

Mean	18.552	S.E. Mean	.770	Std Dev	8.607
Variance	74.088	S.E. Mean	-.463	S.E. Kurt	.430
Skewness	.137	S.E. Skew	.217	Range	38.000
Minimum	0	Maximum	38	Sum	2319.000

Valid observations- 125 Missing observations- 1

SDT SCORE

Mean	178.365	S.E. Mean	5.274	Std Dev	59.203
Variance	3505.002	Kurtosis	.622	S.E. Kurt	.428
Skewness	-1.163	S.E. Skew	.216	Range	245.000
Minimum	-5	Maximum	240	Sum	22474.000

Valid observations- 126 Missing observations- 0

WNMCT SCORE

Mean	50.759	S.E. Mean	2.178	Std Dev	23.053
Variance	531.446	Kurtosis	.861	S.E. Kurt	.453
Skewness	.449	S.E. Skew	.228	Range	128.000
Minimum	1	Maximum	129	Sum	5685.000

Valid observations- 112 Missing observations- 14

AGE

Mean	21.038	S.E. Mean	.447	Std Dev	4.953
Variance	24.534	Kurtosis	7.980	S.E. Kurt	.433
Skewness	2.828	S.E. Skew	.218	Range	25.800
Minimum	17	Maximum	43	Sum	2587.700

Valid observations- 123 Missing observations- 3

TABLE 3
CORRELATIONAL MATRIX OF COGNITIVE AND PERSONAL VARIABLES

	MRT SCORE	SDT SCORE	WNMCT SCORE	ACAD. MAJOR	NONACAD. BKGD. EXP.	ACAD. BKGD. EXP.
MRT SCORE	1.0000 (125) p= .	.5721 (125) p=.000	.1995 (111) p=.018	.1692 (115) p=.035	.4233 (116) p=.000	.2941 (107) p=.001
SDT SCORE		1.0000 (126) p= .	.2460 (112) p=.004	.2635 (116) p=.002	.2520 (117) p=.003	.3366 (108) p=.000
WNMCT SCORE			1.0000 (112) p= .	.0877 (106) p=.186	.0847 (106) p=.194	.2180 (97) p=.016
ACAD. MAJOR				1.0000 (116) p= .	.2447 (113) p=.004	.1511 (102) p=.065
NONACAD. BKGD.EXP.					1.0000 (117) p= .	.4431 (105) p=.000
ACAD. BKGD.EXP.						1.0000 (108) p= .

TABLE 4
CORRELATIONAL MATRIX OF COGNITIVE AND STRATEGY VARIABLES

	MRT SCORE	SDT SCORE	WNMCT SCORE	MRT STRATEGY	SDT STRATEGY	WNMCT STRATEGY
MRT SCORE	1.0000 (125) p= .	.5721 (125) p=.000	.1995 (111) p=.018	.1484 (121) p=.052	-.0016 (120) p=.493	.1202 (118) p=.097
SDT SCORE		1.0000 (126) p= .	.2460 (112) p=.004	.1818 (121) p=.023	-.0133 (121) p=.442	.0155 (119) p=.443
WNMCT SCORE			1.0000 (112) p= .	.0367 (109) p=.352	.0236 (109) p=.404	.2082 (108) p=.015
MRT STRATEGY				1.0000 (121) p= .	.1387 (120) p=.065	.1554 (118) p=.046
SDT STRATEGY					1.0000 (121) p= .	.1390 (118) p=.067
WNMCT STRATEGY						1.0000 (119) p= .

TABLE 5
STEPWISE MULTIPLE REGRESSION ANALYSIS
FOR VARIABLES EXPLAINING SPATIAL ORIENTATION
(BASED ON MRT)

STEP	VARIABLE	R^2 [a]	B [b]	B [c]
1	SDT Score	.32	.56	.41[d]
2	Gender	.40	-.31	-.28[d]
3	Nonacad. Bkgd. Exp.	.47	.27	.31[d]
4	MRT Strategy	.49	—	-.05
5	Major	.49	—	-.03
6	WNMCT Score	.49	—	.07
7	Age	.49	—	-.05
8	Acad. Bkgd. Exp.	.49	—	-.07

a Explained variance, cumulative percentage

b Standard regression coefficients for the model, i.e.,beta weights; all coefficients are initial beta weights.

c Final beta weights accompanying all variables in the equation

d t ratio significance ($p < .01$)

TABLE 6
STEPWISE MULTIPLE REGRESSION ANALYSIS
FOR VARIABLES EXPLAINING SPATIAL VISUALIZATION
(BASED ON SDT)

STEP	VARIABLE	R^2 [a]	B [b]	B [c]
1	MRT Score	.31	.56	.48[d]
2	WNMCT Score	.35	.20	.17[e]
3	SDT Strategy	.41	—	.07
4	Major	.41	—	.11
5	Age	.41	—	-.12
6	Acad. Bkgd. Exp.	.41	—	.17
7	Gender	.41	—	.04
8	Nonacad. Bkgd. Exp.	.41	—	-.03

a Explained variance, cumulative percentage

b Standard regression coefficients for the model, i.e., beta weights; all coefficients are initial beta weights.

c Final beta weights accompanying all variables in the equation

d t ratio significance ($p < .001$)

e t ratio significance ($p < .10$)

TABLE 7
DESCRIPTIVE STATISTICS FOR SPATIAL VARIABLES -- MAT 102

SDT#1 SCORE		SDT#2 SCORE	
Mean	100.233	Mean	146.244
S.E. Mean	6.027	S.E. Mean	8.558
Std. Dev.	46.683	Std. Dev.	57.409
Maximum	180	Maximum	240
Minimum	- 11	Minimum	- 2
Range	191	Range	242
n	60	n	45

MRT#1 SCORE		MRT#2 SCORE	
Mean	12.483	Mean	15.222
S.E. Mean	.811	S.E. Mean	1.148
Std. Dev.	6.286	Std. Dev.	7.702
Maximum	29	Maximum	36
Minimum	2	Minimum	0
Range	27	Range	36
n	60	n	45

TABLE 8
DESCRIPTIVE STATISTICS FOR SPATIAL VARIABLES -- MAT 103

SDT#1 SCORE		SDT#2 SCORE	
Mean	115.769	Mean	142.356
S.E. Mean	9.208	S.E. Mean	11.503
Std. Dev.	66.401	Std. Dev.	77.166
Maximum	240	Maximum	240
Minimum	- 7	Minimum	- 25
Range	247	Range	265
n	52	n	45

MRT#1 SCORE		MRT#2 SCORE	
Mean	15.577	Mean	17.711
S.E. Mean	1.191	S.E. Mean	1.429
Std. Dev.	8.587	Std. Dev.	9.586
Maximum	40	Maximum	40
Minimum	0	Minimum	2
Range	40	Range	38
n	52	n	45

TABLE 9
CORRELATIONAL MATRIX OF PRETEST SPATIAL SCORES
AND PERSONAL VARIABLES -- MAT 102

	SDT#1 SCORE	MRT#1 SCORE	AGE	GENDER	ACAD. CLASS	ACAD. MAJOR[a]
SDT#1 SCORE	1.0000 (60) p=.	.2118 (60) p=.052	-.1812 (60) p=.083	.0605 (60) p=.323	.0005 (53) p=.499	. (53) p=.
MRT#1 SCORE		1.0000 (60) p=.	-.1914 (60) p=.071	-.0187 (60) p=.444	-.2401 (53) p=.042	. (53) p=.
AGE			1.0000 (60) p=.	.0050 (60) p=.485	-.0527 (53) p=.354	. (53) p=.
GENDER				1.0000 (60) p=.	-.2459 (53) p=.038	. (53) p=.
ACAD. CLASS					1.0000 (53) p=.	. (53) p=.
ACAD. MAJOR						1.0000 (53) p=.

a A uniform code among subjects precluded coefficient calculations.

TABLE 10
CORRELATIONAL MATRIX OF PRETEST SPATIAL SCORES
AND PERSONAL VARIABLES -- MAT 103

	SDT#1 SCORE	MRT#1 SCORE	AGE	GENDER	ACAD. CLASS	ACAD. MAJOR
SDT#1 SCORE	1.0000 (52) p=.	.5359 (52) p=.000	-.2677 (52) p=.027	-.0386 (52) p=.393	-.3065 (52) p=.014	-.1439 (42) p=.182
MRT#1 SCORE		1.0000 (52) p=.	-.1494 (52) p=.145	-.3437 (52) p=.006	-.1121 (52) p=.214	-.1110 (42) p=.242
AGE			1.0000 (52) p=.	.1850 (52) p=.095	.5967 (52) p=.000	.1987 (42) p=.104
GENDER				1.0000 (52) p=.	.0221 (52) p=.438	.1348 (42) p=.197
ACAD. CLASS					1.0000 (52) p=.	.3868 (42) p=.006
ACAD. MAJOR						1.0000 (42) p=.

TABLE 11
CORRELATIONAL MATRIX OF PRETEST SPATIAL SCORES, PERSONAL VARIABLES, AND RETROSPECTIVE REPORT VARIABLES (QUESTIONNAIRE I) — MAT 102

	SDT#1 SCORE	MRT#1 SCORE	NONACAD. BKGD.EXP.	ACAD. BKGD.EXP.	SELF RPT. SDT#1	DIREC. SDT#1	SELF RPT. MRT#1	DIREC. MRT#1
SDT#1 SCORE	1.0000 (60) p=.	.2118 (60) p=.052	-.1193 (53) p=.198	.3190 (53) p=.010	.4884 (53) p=.000	.1647 (52) p=.122	-.0074 (48) p=.480	.1751 (48) p=.117
MRT#1 SCORE		1.0000 (60) p=.	-.0706 (53) p=.308	.1187 (53) p=.199	.2019 (53) p=.074	.0815 (53) p=.283	.3796 (48) p=.004	.1433 (48) p=.166
NONACAD. BKGD.EXP.			1.0000 (53) p=.	.1948 (53) p=.081	.1959 (53) p=.080	-.3539 (52) p=.005	.3844 (48) p=.003	-.4117 (48) p=.002
ACAD. BKGD.EXP.				1.0000 (53) p=.	.0848 (53) p=.273	.0563 (52) p=.346	.0724 (48) p=.312	.0555 (48) p=.354
SELF RPT. SDT#1					1.0000 (53) p=.	.2104 (52) p=.067	.4447 (48) p=.001	.1628 (48) p=.134
DIREC. SDT#1						1.0000 (52) p=.	-.0639 (47) p=.335	.9590 (48) p=.000
SELF RPT. MRT#1							1.0000 (48) p=.	-.0279 (47) p=.426
DIREC. MRT#1								1.0000 (48) p=.

TABLE 12
CORRELATIONAL MATRIX OF PRETEST SPATIAL SCORES, PERSONAL VARIABLES, AND RETROSPECTIVE REPORT VARIABLES (QUESTIONNAIRE I) — MAT 103

	SDT#1 SCORE	MRT#1 SCORE	NONACAD. BKGD.EXP.	ACAD. BKGD.EXP.	SELF RPT. SDT#1	DIREC. SDT#1	SELF RPT. MRT#1	DIREC. MRT#1
SDT#1 SCORE	1.0000 (52) p=.	.5359 (52) p=.000	.1935 (49) p=.091	.3595 (50) p=.005	.6465 (50) p=.000	.0994 (45) p=.258	.3337 (47) p=.011	-.0345 (43) p=.413
MRT#1 SCORE		1.0000 (52) p=.	.1550 (49) p=.144	-.0237 (50) p=.435	.6001 (50) p=.000	-.0146 (45) p=.462	.6989 (47) p=.000	-.0298 (43) p=.425
NONACAD. BKGD.EXP.			1.0000 (49) p=.	.2922 (48) p=.022	.0878 (47) p=.279	-.2422 (43) p=.059	-.0433 (44) p=.390	.1485 (40) p=.180
ACAD. BKGD.EXP.				1.0000 (50) p=.	.0605 (48) p=.341	.2679 (43) p=.041	.0151 (45) p=.461	.1834 (41) p=.126
SELF RPT. SDT#1					1.0000 (50) p=.	.3308 (45) p=.013	.6941 (47) p=.000	.1391 (43) p=.187
DIREC. SDT#1						1.0000 (45) p=.	.3050 (42) p=.025	.5379 (40) p=.000
SELF RPT. MRT#1							1.0000 (47) p=.	.0686 (43) p=.331
DIREC. MRT#1								1.0000 (43) p=.

TABLE 13
CORRELATIONAL MATRIX OF POSTTEST SPATIAL SCORES, RETROSPECTIVE REPORT VARIABLES (QUESTIONNAIRE II), AND EXAM — MAT 102

	SDT#2 SCORE	MRT#2 SCORE	SELF RPT. SDT#2	DIREC. SDT#2	SELF RPT. MRT#2	DIREC. MRT#2	FINAL EX.GRD.
SDT#2 SCORE	1.0000 (45) p=.	.4832 (45) p=.000	.2847 (45) p=.029	.2419 (43) p=.059	.0639 (45) p=.338	.1178 (43) p=.226	.3612 (45) p=.007
MRT#2 SCORE		1.0000 (45) p=.	.0830 (45) p=.294	-.0074 (43) p=.481	.1354 (45) p=.188	.2197 (43) p=.078	.1845 (45) p=.113
SELF RPT. SDT#2			1.0000 (45) p=.	.8390 (43) p=.000	.6129 (45) p=.000	.3831 (43) p=.006	.0708 (45) p=.322
DIREC. SDT#2				1.0000 (43) p=.	.6434 (43) p=.000	.6092 (42) p=.000	.0817 (43) p=.301
SELF RPT. MRT#2					1.0000 (45) p=.	.8257 (43) p=.000	-.0710 (45) p=.322
DIREC. MRT#2						1.0000 (43) p=.	-.1293 (43) p=.204
FINAL EX.GRD.							1.0000 (57) p=.

TABLE 14
CORRELATIONAL MATRIX OF POSTTEST SPATIAL SCORES, RETROSPECTIVE REPORT VARIABLES (QUESTIONNAIRE II), AND EXAM -- MAT 103

	SDT#2 SCORE	MRT#2 SCORE	SELF RPT. SDT#2	DIREC. SDT#2	SELF RPT. MRT#2	DIREC. MRT#2	FINAL EX.GRD.
SDT#2 SCORE	1.0000 (45) p=.	.6379 (45) p=.000	.1336 (38) p=.212	.2618 (36) p=.061	.3024 (36) p=.037	.0865 (35) p=.311	.2704 (44) p=.038
MRT#2 SCORE		1.0000 (45) p=.	.2579 (38) p=.059	.1288 (36) p=.227	.6162 (36) p=.000	.4275 (35) p=.005	.3410 (44) p=.012
SELF RPT. SDT#2			1.0000 (38) p=.	.6787 (36) p=.000	.4133 (36) p=.006	.1508 (35) p=.194	.2001 (37) p=.117
DIREC. SDT#2				1.0000 (36) p=.	.3149 (34) p=.035	.2878 (34) p=.049	.1525 (35) p=.191
SELF RPT. MRT#2					1.0000 (36) p=.	.6868 (35) p=.000	.2928 (35) p=.044
DIREC. MRT#2						1.0000 (35) p=.	.1217 (34) p=.247
FINAL EX.GRD.							1.0000 (56) p=.

TABLE 15
CORRELATED T TESTS FOR SPATIAL VARIABLES — MAT 102

VARIABLE		NUMBER OF CASES	MEAN	STD DEV	DIFFERENCE MEAN	T VALUE	DEGREES OF FREEDOM	TWO-TAIL PROBABILITY
SDT#1	Score		100.4889	41.762				
		45			-45.7556	-8.07	44	.000
SDT#2	Score		146.2444	57.409				
MRT#1	Score		12.9778	6.362				
		45			- 2.2444	-2.38	44	.022
MRT#2	Score		15.2222	7.702				

TABLE 16
CORRELATED T TESTS FOR SPATIAL VARIABLES -- MAT 103

VARIABLE		NUMBER OF CASES	MEAN	STD DEV	DIFFERENCE MEAN	T VALUE	DEGREES OF FREEDOM	TWO-TAIL PROBABILITY
SDT#1	Score		115.7895	69.255				
		38			-27.5789	-5.41	37	.000
SDT#2	Score		143.3684	78.180				
MRT#1	Score		15.5526	7.948				
		38			- 2.8421	-2.80	37	.008
MRT#2	Score		18.3947	9.719				

General Discussion

Although correlated, three-dimensional spatial visualization and spatial orientation skills are important to success in high spatial careers. For example, the architect should be able to mentally transcend two-dimensional diagrams to see three-dimensional structures. Seeing these structures from different angles as they appear intact is also a necessary skill for the architect. Hence, the rationale for his/her visualization and orientation, respectively, is provided. Yet, the chemist should be able to mentally envision and manipulate three-dimensional molecular and atomic models. The physicist should be able to mentally comprehend the new dimensions resulting from shear strain upon an object. Many more examples exist.

The question, however, is how does a school student develop an aptitude for these skills if that student is to enjoy equal occupational opportunity in these kinds of careers? Partial answers surfaced in two multiple regression analyses. Although the most important predictor of SV skill is SO skill and vice versa, for spatial visualization, academic experiences are important; for spatial orientation, nonacademic experiences are important. Males, however, significantly outperformed females in mental rotation (unstandardized coefficient B= -5.991771). Coupled with the fact that nonacademic experiences are critical to such reasoning, it seems reasonable to conclude the males, who tend to play with blocks when they are young, would be more adept at mental block processing. Parenthetically speaking, my best MRT performer was a male student in my West Chester study, who scored a perfect 40 on the MRT twice. When asked about his extraordinary success, he attributed it to playing with the Rubik's cube games. Male dominance on the MRT has been documented in other studies (Vandenberg and Kuse, 1978; Baker, 1987; also see McGee, 1979).

Regarding just which strategies prove more efficient for SV and SO aptitude, the multiple regressions showed no evidence that spatial strategies in either SV or SO were important predictors of performance. It appears that there is a lack of consensus among the best spatializers. Nonetheless, for MRT performance, analogue strategies yielded higher scores on the average. For SDT performance, either mental folding or use of mechanical drawing strategies were fruitful. The latter finding was based on my personal examination of the profiles of twelve subjects who scored 30 or above on the MRT and at least 221 on the SDT.

Based on the cited findings, it seems that schools should include more spatially enriching experiences for students in their respective curricula. A good time to begin a spatial program would be when youngsters are in the elementary grades, particularly when children are at the concrete operational stage in grades 2 through 6. Girls, especially, should be encouraged to perform such activities as assembling clocks in science classes and computing answers with Dienes blocks and Cuisenaire rods in math classes. A host of activities should be incorporated into the science and mathematics curricula.

Nonetheless, there is some encouragement from the second study that students can be taught spatial aptitudes in higher grades, even in college. Those students who chose to take both pretests and posttests in spatial skills and who, on the average, showed that they did do better after a lengthy period of spatial reasoning, afford some positive evidence toward that fact. However, a close inspection of student opinions gathered from the second questionnaire hinted to the fact that practice effects had some bearing on the outcome of the study. Very few students in both classes attributed their better performance in the posttest to the spatial training.

In conclusion, on the practical front, these exploratory studies serve to herald the need for earlier intervention of spatial material in the academic curriculum. And, since even college students are still undecided about career selection, spatial training should be extended wherever possible to the collegiate curriculum. On the theoretical front, more studies in which randomly selected students of various ages are tested individually for spatial skills and strategies are needed. Perhaps, introspective reports would prove more helpful to efficient skill differentiation than retrospective reports. Perhaps, subsequent canonical analysis based on more precisely delineated skills and strategies would provide greater insight. Also, randomly selected and randomly assigned subjects of all ages should be exposed to spatial training. To ensure that students understand the directions, testing should be done individually or in small groups. To circumvent a possible practice contamination, parallel tests, not identical tests, should be used. Last, but not least, an analysis of covariance statistical procedure would be more powerful in a true experimental design.

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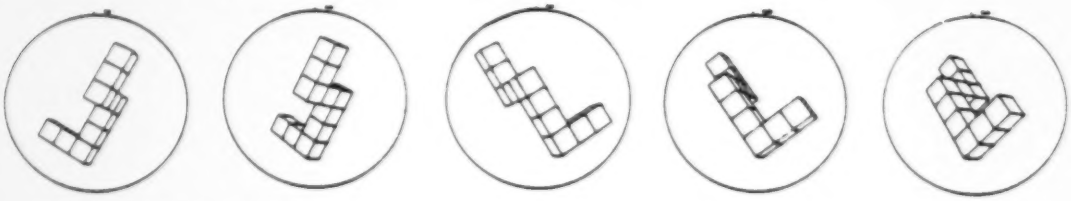
APPENDIX

Name _____

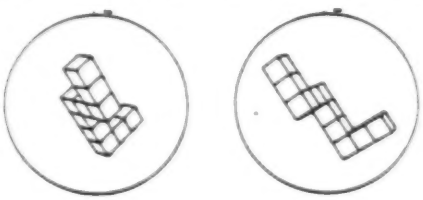
M.R.T. Test Date _____

_____

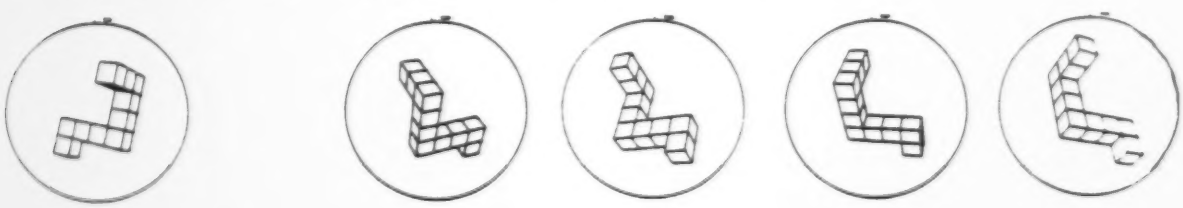
This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles. An illustration of this principle is given below, where the same single object is given in five different positions. Look at each of them to satisfy yourself that they are only presented at different angles from one another.



Below are two drawings of new objects. They cannot be made to match the above five drawings. Please note that you may not turn over the objects. Satisfy yourself that they are different from the above.



Now let's do some sample problems. For each problem there is a primary object on the far left. You are to determine which two of four objects to the right are the same object given on the far left. In each problem always <u>two</u> of the four drawings are the same object as the one on the left. You are to put Xs in the boxes below the correct ones, and leave the incorrect ones blank. The first sample problem is done for you.



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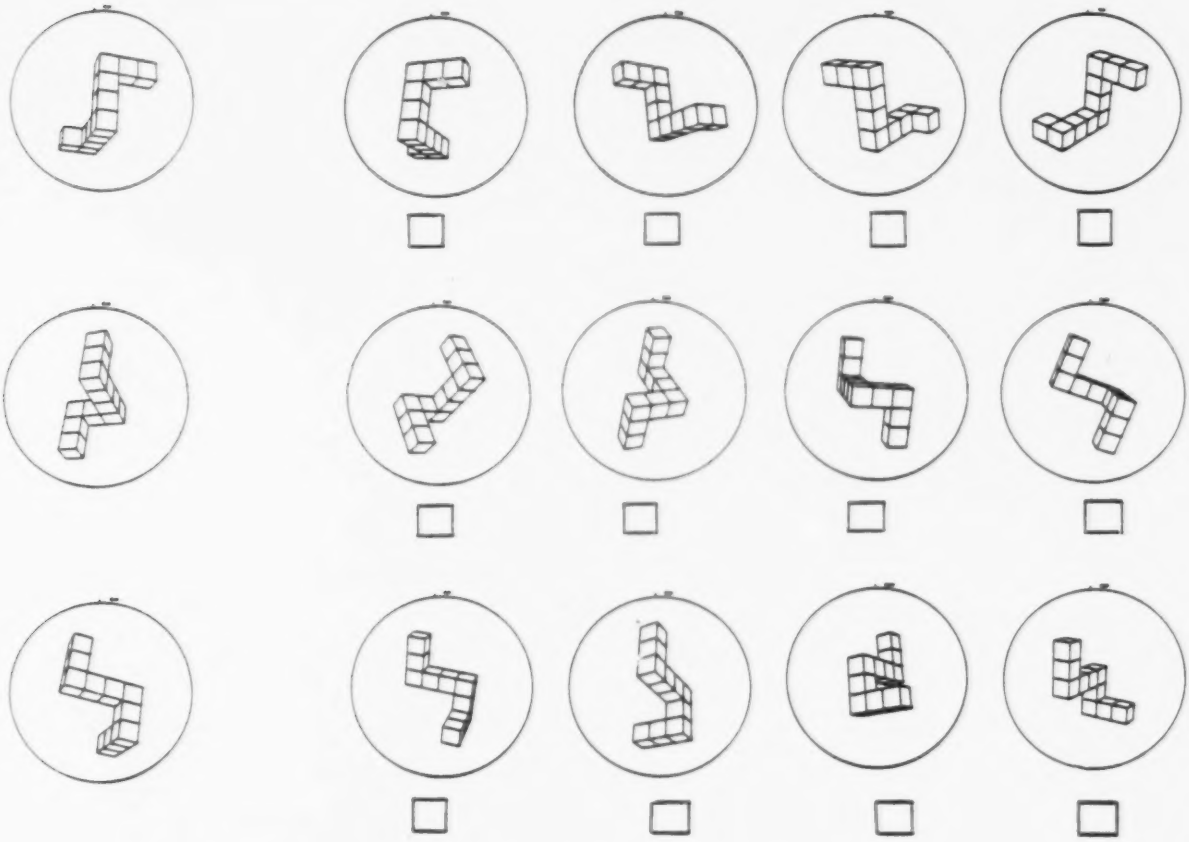
Adapted by S.G. Vandenberg, University of Colorado, July 15, 1971
Revised instructions by H. Crawford, U. of Wyoming, September, 1979

Do the rest of the sample problems yourself. Which two drawings of the four on the right show the same object as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.



Answers: (1) first and second drawings are correct
(2) first and third drawings are correct
(3) second and third drawings are correct

This test has two parts. You will have 3 minutes for each of the two parts. Each part has two pages. When you have finished Part I, STOP. Please do not go one to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

Work as quickly as you can without sacraficing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.

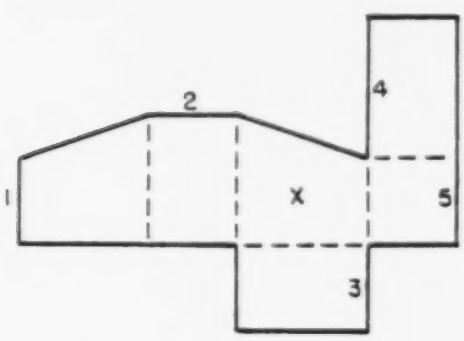
DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

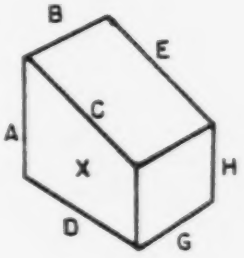
Name _____

SURFACE DEVELOPMENT TEST — VZ-3

In this test you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is of a piece of paper which can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.





1:	H
2:	
3:	
4:	C
5:	

NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.

In the above problem, if the side with edge 1 is folded around to form the back of the object, then edge 1 will be the same as edge H. If the side with edge 5 is folded back, then the side with edge 4 may be folded down so that edge 4 is the same as edge C. The other answers are as follows: 2 is B; 3 is G; and 5 is H. Notice that two of the answers can be the same.

Your score on this test will be the number of correct letters minus a fraction of the number of incorrect letters. Therefore, it will <u>not</u> be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have <u>6 minutes</u> for each of the two parts of this test. Each part has 2 pages. <u>When you</u> have finished Part 1 (pages 2 and 3), STOP. Please do not go on to Part 2 until you are asked to do so.

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Name_____ Date_____

Whole Numbers Mental Computation Test

This examination contains two subtests. The first subtest consists of 16 problems in addition and subtraction. The second subtest consists of 16 problems in multiplication and division. Each problem is accompanied by 5 choices. Circle the letter of the correct answer.

All problems must be done mentally. Do not use your pencil or pen to mark the carry digits, the borrow digits, the partial products, or the partial quotients. Use your writing instrument only to circle the correct alternative for each problem.

The subtests are separate. You will be given 5 minutes to complete each subtest. Work as rapidly and as accurately as possible. Do not make wild guesses. There is a penalty for incorrect answers. If you finish the addition-subtraction subtest before time is called, do not go on to the second subtest. Likewise, if you finish the multiplication-division subtest before time is called, do not go back to the first subtest.

Sample Items

Subtest 1

Addition

723	a	3171
851	b	3251
406	c	3151
264	(d)	3161
917	e	3261

Subtraction

8343	a	2436
-5917	(b)	2426
	c	2336
	d	3336
	e	3326

Subtest 2

Multiplication

425	a	14,300
X 36	b	15,200
	(c)	15,300
	d	14,200
	e	16,300

Division

27)349	a	12 R 22
	b	13 R 3
	c	12 R 23
	d	13 R 2
	(e)	12 R 25

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